



## Dramatically Improve the Safety Performance of Li ion Battery Separators and Reduce the Manufacturing Cost Using UV Curing and High Precision Coating Technologies

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June 9, 2016

**Project ID # ES243**

## Project Overview

### Timeline:

Start Date: 10/01/2014

End Date: 6/30/2017

Percent Complete: 50%

### Budget:

DOE Share \$1,955,000

Cost share \$ 399,000

FY 15 \$ 376,556

FY 16 \$1,019,444

### Barriers to Electric Vehicles addressed by this project:

1. **Battery Performance**, improving performance as well as safety
2. **Cost**, reducing costs and improving quality of producing ceramic coatings on separators

### Partners

Argonne National Laboratory

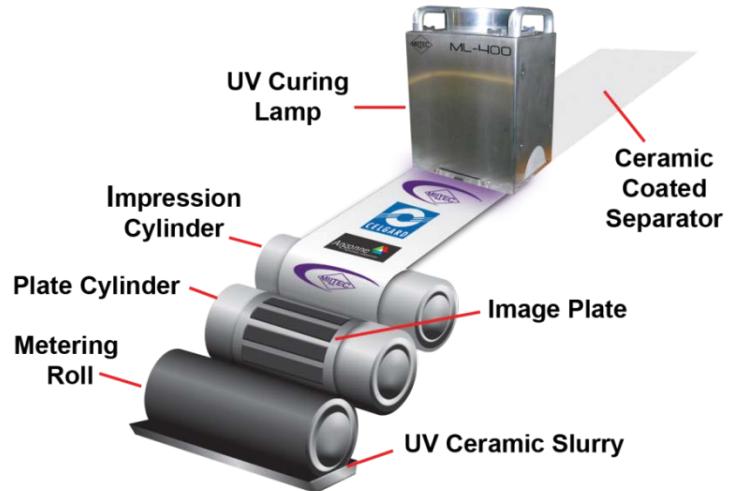
Celgard, LLC



# Relevance and Project Objectives

## Proposed Project Objectives/Goals:

Improve the shutdown and reduce the risk of thermal runaway and fire, without sacrificing ion charge and discharge rates, and to reduce the manufacturing ceramic coated separators costs by 50%.



## Project's Key Idea/Takeaway:

A revolutionary technology to improve performance and reduce cost of ceramic coated separators.

## Why Ceramic Coated Separators and Why UV?

- **General Safety**
  - Reduce Dendrite Growth/Penetration
  - Improve long term capacity by scavenging cathode and electrolyte decomposition products preventing them from covering anode
  - Prevent separator shrinkage thermal runaway
- **UV Specific**
  - Do not appreciably reduce porosity (pattern UV)
  - High Voltage Stability (UV crosslinking)
  - Significantly less shrinkage (UV)
  - Easier process to control (UV)



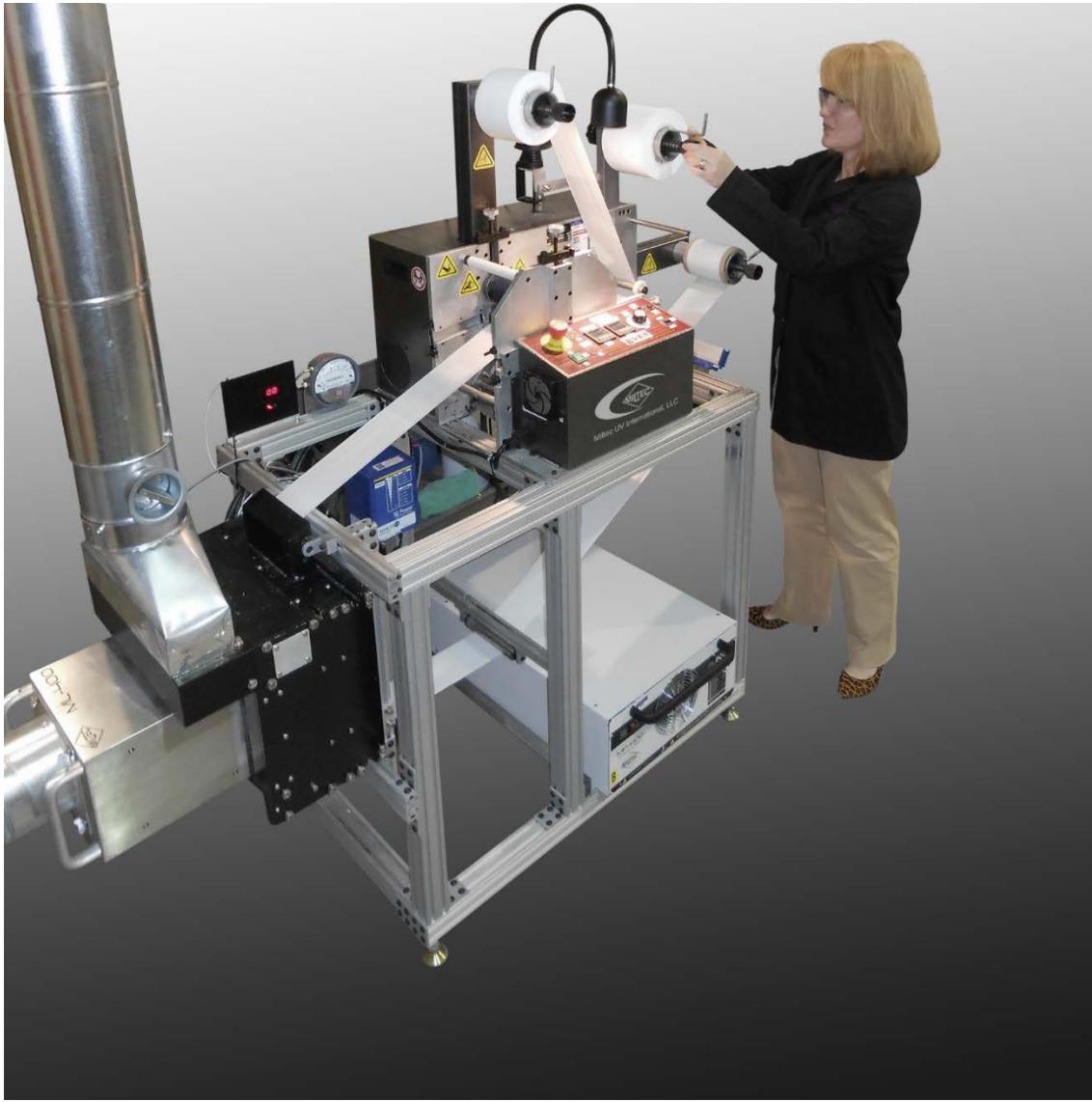
## Approach

- **Benchtop:** Develop UV binder chemistry with good adhesion; resulting low shrinkage and minimal loss of porosity for ceramic coated separators as means to improve battery safety
- **Lab Press:** Prove coatings and method work in coatings rolls.
- **Outside Validation:** confirm performance on PP, PE, and trilayer base separator
- **Commercial Scale:** Demonstrate performance when printed with a high speed printer

Milestones	Planned Completion	Status
<b>Budget Period 1</b>		
Project Management Plan	10/16/2014	complete
UV curable binder characterization	12/15/2014	complete
Adjust UV Curable Binder formulation for printing applications	03/15/2015	complete
Printing Pattern Characterization	06/24/2015	complete
Separator Coating Laboratory Testing Complete	08/24/2015	complete
Complete Separator Electrochemical Evaluation (Go/No-Go)	09/30/2015	complete
<b>Budget Period 2</b>		
Complete Initial Printing Press application Validation Tests	12/15/2015	complete
Initiate Purchase of Commercial Scale Press	03/18/2016	complete
Complete Press Design	06/24/2016	
Begin Press Shakedown	09/26/2016	
Complete Final Printing Press Tests	06/26/2017	
Complete Cost Model	12/10/2016	
Complete Cost Reduction Analysis	03/12/2017	



# Laboratory Press Printing at 200 fpm with small footprint



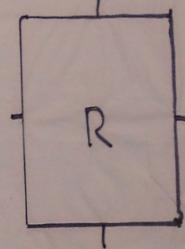
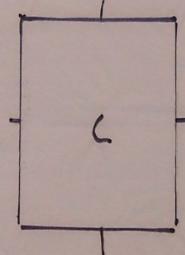
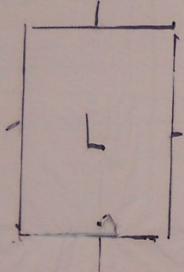
- Sub-micrometer Coating Thickness Control
- Thinner Coatings,
  - Less Weight
  - More Ion Flow
  - Reduced Cost
- Patterns for Higher Ion Flow
- Versatile, able to Print or Coat
- Commercial scale equipment readily available

## Accomplishments

- Developed solid UV coatings for PE, PP, and Trilayer separators with <5% shrinkage at 150°C and Gurley increases  $\leq 10\%$ .
- Tested high voltage stability of UV coating verified in 4.8 V full cell screening test
- Printed patterned coatings for reduced vehicle weight and higher ion flow, while maintaining shrinkage <5% at 150°C

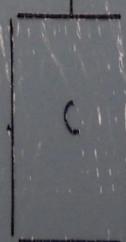


# **16 µm Trilayer Separator after 150°C for 1 hr**



**UV Coated, 3% MD  
Shrinkage**

XPL18-34



**Uncoated, 25% MD  
Shrinkage**

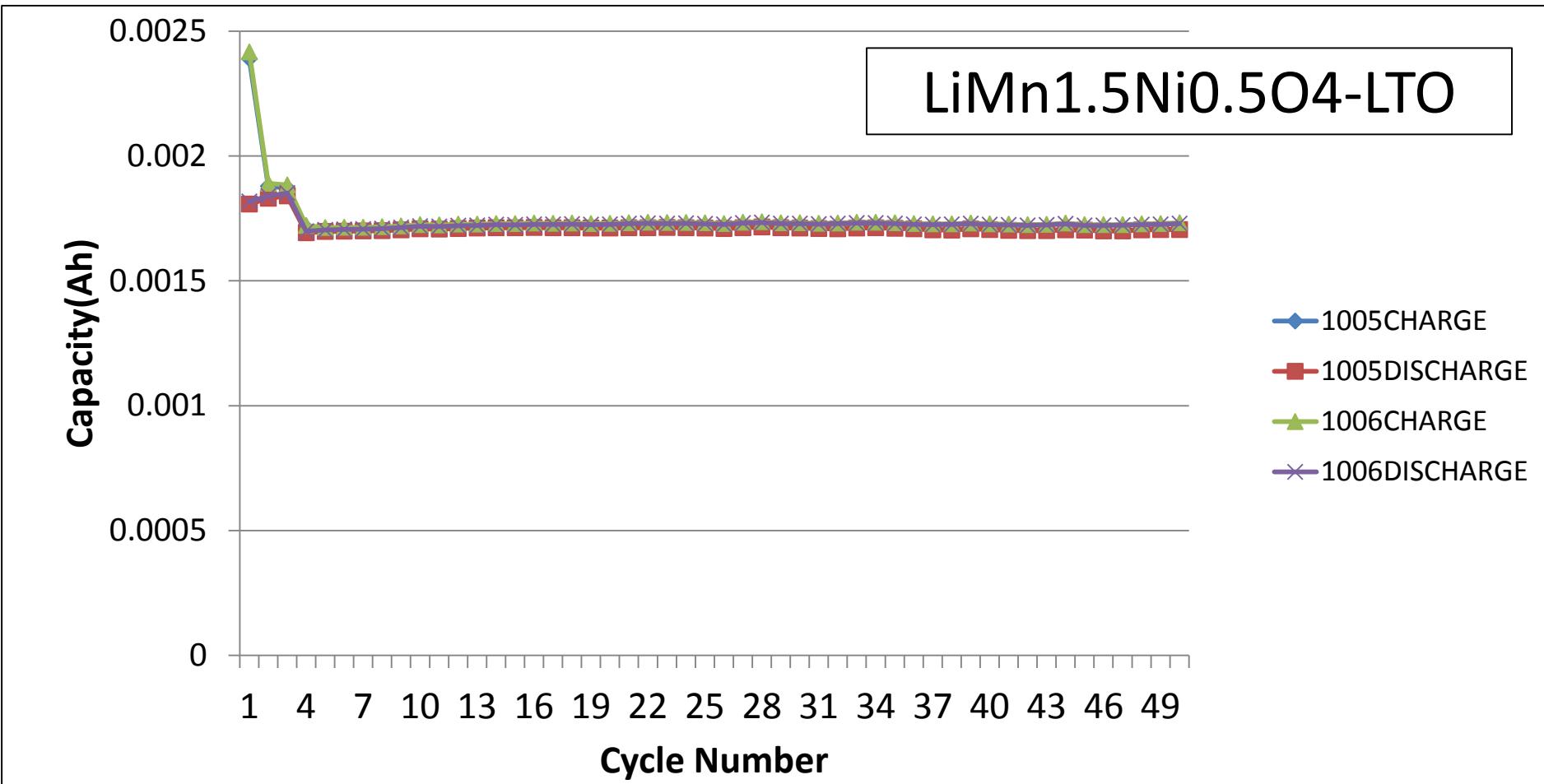
150 °C

## Accomplishments

- Developed solid UV coatings for PE, PP, and Trilayer separators with <5% shrinkage at 150°C and Gurley increases ≤ 10%.
- Tested high voltage stability of UV coating verified in 4.8 V full cell screening test
- Printed patterned coatings for reduced vehicle weight and higher ion flow, while maintaining shrinkage <5% at 150°C



# Stable 4.8 V cell with UV Ceramic Coated Separator



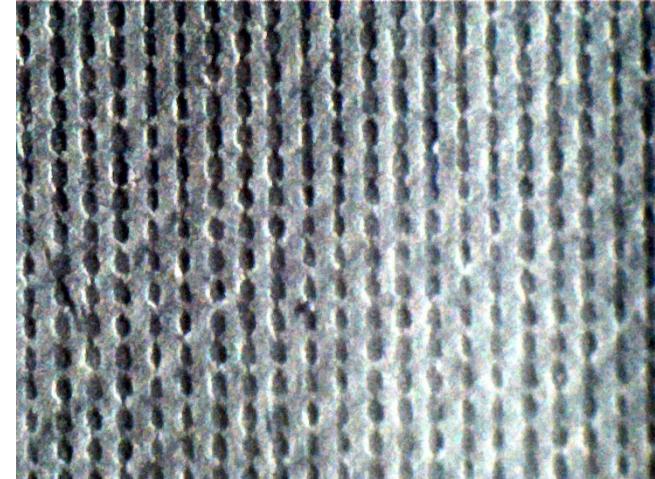
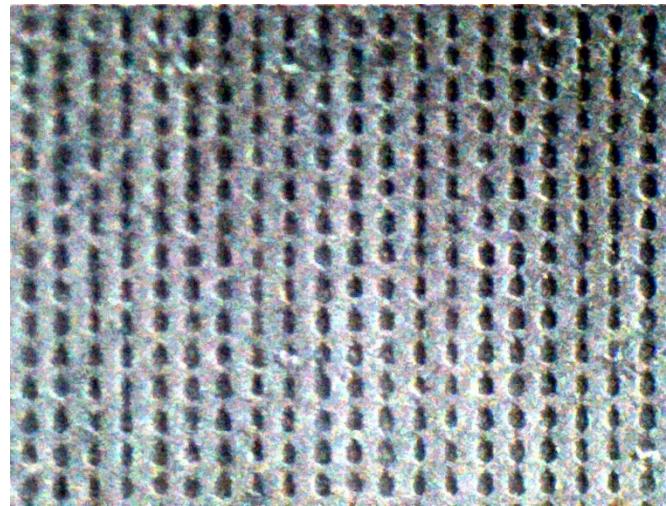
## Accomplishments

- Developed solid UV coatings for PE, PP, and Trilayer separators with <5% shrinkage at 150°C and Gurley increases  $\leq 10\%$ .
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- Printed patterned coatings for reduced vehicle weight and higher ion flow, while maintaining shrinkage <5% at 150°C



# **9 µm PE Printed Pattern Protection + Ion Flow**

- **Flexographic Print**
- **Uncoated HPGurley = 6 s**
- **Coated HPGurley = 10 s**
- **Coating Thickness = 3 µm**



## Accomplishments

- Developed solid UV coatings for PE, PP, and Trilayer separators with MD shrinkage @ 150°C below 3.0% and often below 1.0% and with Gurley increases  $\leq$  10% above uncoated separator.
- Tested high voltage stability of UV coating verified in 4.8 V full cell screening test
- Printed patterned coatings for reduced vehicle weight and higher ion flow, while maintaining shrinkage <5% at 150°C



## Partners



**Prepare cells made with Miltec UV  
ceramic coated separator and  
evaluate performance**

**Dr. Khalil Amine, ANL**



**Conduct tests to confirm adhesion,  
strength, shrinkage and porosity of  
Miltec UV ceramic coated samples**

**Dr. John Zhang, Celgard**

# Remaining Challenges Future Work

- Confirm advantages of printed coating
- Develop coatings with additional shut down temperatures
- Complete and operate a custom commercial prototype press
- Confirm ability for high speed coating with superior coating uniformity, tension, and consistency.



## Summary

- UV ceramic coatings are capable of achieving all the important properties of a ceramic coated separator:
  - <1% shrinkage
  - ≤10% increase in Gurley
  - Excellent adhesion
  - Low coating weight and
  - High speed processing +200 fpm.
- UV process leads to short web path, less unsupported web, which will lead to better yields and less scrap.
- UV ceramic coatings are crosslinked, which benefits high voltage and chemical resistance for future batteries.
- UV with printing technologies may lead to faster charge/discharge batteries & less weight, without sacrificing safety.

